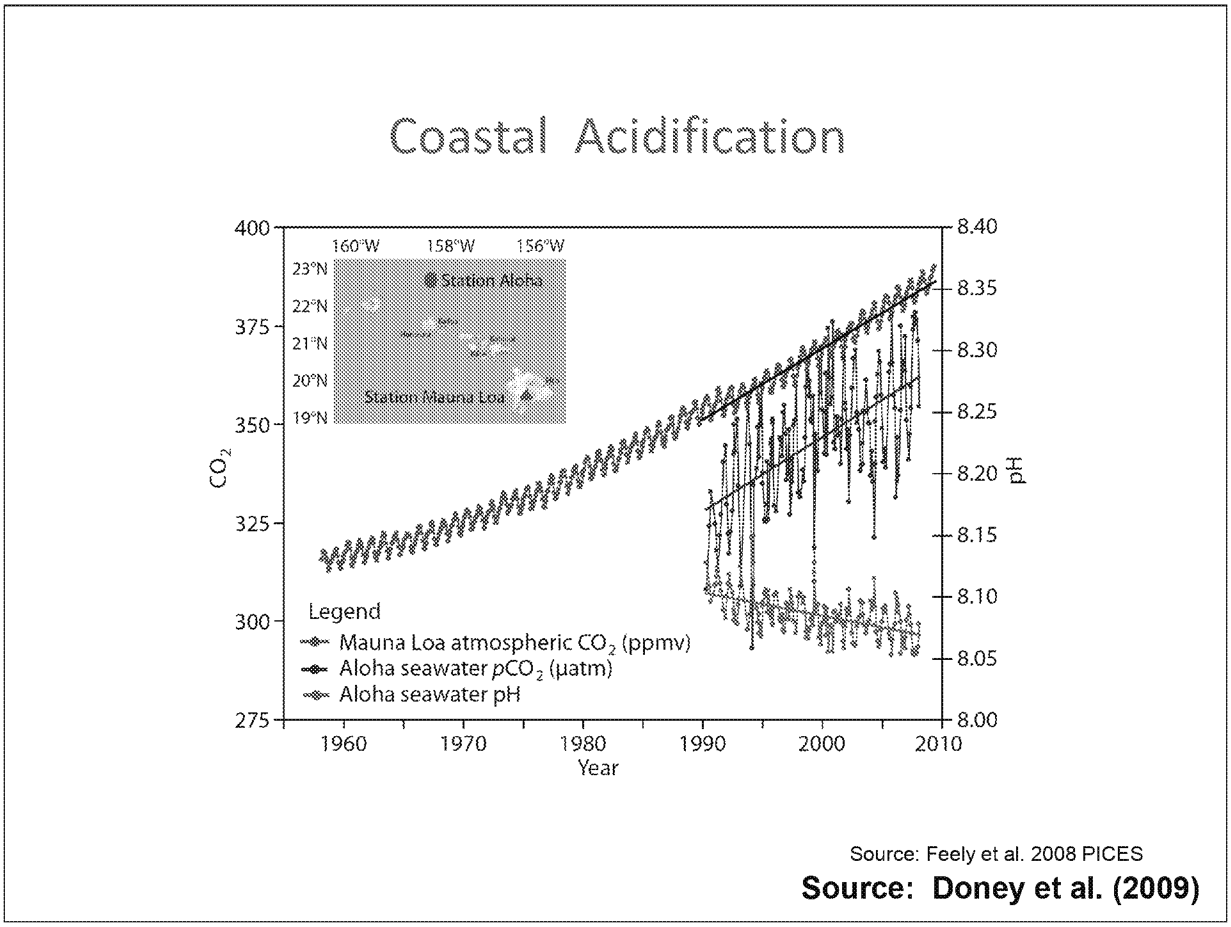
Toward a unified understanding of coastal acidification processes in Puget Sound:
Exploring synergies between cultural eutrophication, ocean acidification, and natural variability in critical nearshore environments

Nice photo of puget sound a background

Stephen Pacella

Cheryl Brown

7 July 2015

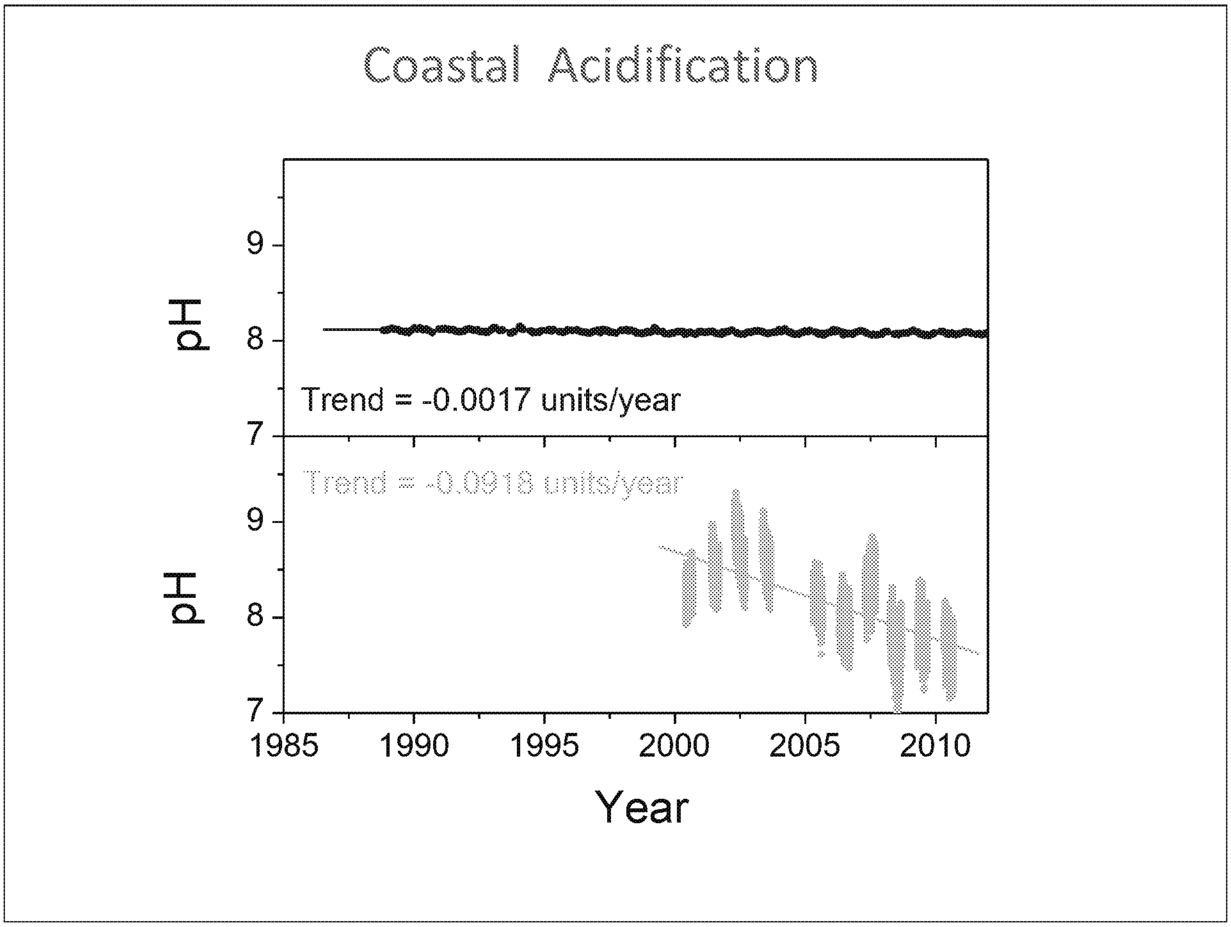


This is a time series of atmospheric CO2 levels since about the 1960s at Mauna Loa in Hawaii.
As CO2 in the atmosphere has increased, so has the concentration of CO2 (pCO2) in the ocean, with a resulting increase in acidity as measured on the pH scale.
pH has decreased by about 0.02 units per decade, or 0.1 unit since the industrial era.

Projected decreases are a further 0.2 - 0.3 units by 2100, yielding surface ocean pH lower than in the last 20,000,000 years.
The change in the chemistry in the ocean also has reduce the availability of carbonate ions in seawater, which influences calcification of marine organisms with shells.

When CO2 enters the ocean, it reacts with water to form carbonic acid, releasing hydrogen ions and lowering the ocean's pH.
A portion of the hydrogen ions released by carbonic acid reacts with the ocean's reserves of carbonate ions to produce additional bicarbonate.
This reaction depletes the ocean's reserves of carbonate ions

Calcifiers depend on carbonate ions for their survival; they are essential "building blocks" they use to build shells or skeletons. Reduced dissolved carbonate ion concentrations leads to a reduction in the saturation states of aragonite and calcite (biologically important forms of calcium carbonate), which compromises these organisms' ability to form shells and skeletons.



This slide is animated (click through it).
The top slide shows open ocean time series from Hawaii.
Then Wootton data appears; then next click is the top panel is re-scaled.
The point, coast acidification is occurring at a much more rapid rate in some coastal areas than in the open ocean.
At this point, the cause is unknown

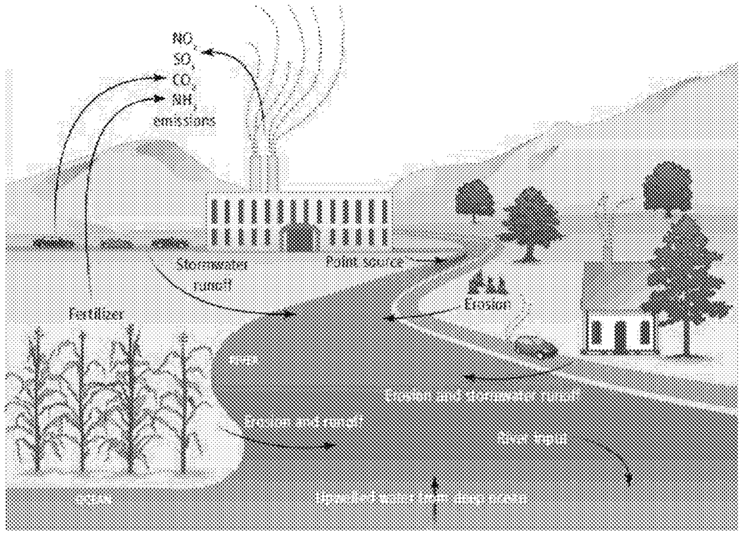
POLICYFORUM

OCEANS

Mitigating Local Causes of Ocean Acidification with Existing Laws

Even as global and national efforts struggle to mitigate CO_2 emissions, local and state governments have policy tools to address "hot spots" of ocean acidification.

R. P. Kelly,[1*†] M. M. Foley,[1*] W. S. Fisher,[2] R. A. Feely,[3] B. S. Halpern,[4] G. G. Waldbusser,[5] M. R. Caldwell[1]



Contributors to ocean acidification. In addition to global atmospheric CO_2, this figure depicts the major local (within 100 km) sources contributing to coastal ocean acidification.

27 MAY 2011 VOL 332 SCIENCE www.sciencemag.org

"Local & state governments have both the authority and motive to address many stressors that drive or exacerbate acidification conditions"

↓

Clean Water Act

Some of the potential causes are changes in upwelling, nutrient loading, changes in freshwater inflow, atmospheric emissions, etc.
http://www.sciencemag.org/content/332/6033/1036.full
Although increasing anthropogenic CO2 inputs drive acidification at global scales, local acidification disproportionately affects coastal ecosystems and the communities that rely on them. We describe policy options by which local and state governments—as opposed to federal and international bodies—can reduce these local and regional "hot spots" of ocean acidification.

Several studies document acidification hot spots, patches of ocean water with significantly depressed pH levels relative to historical baselines occurring at spatial scales of tens to hundreds of square kilometers. These coastal hot spots may be due to nonuniform changes in circulation and biological processes, and precipitation runoff in concert with globally increased atmospheric CO2. Freshwater inputs, pollutants, and soil erosion can acidify coastal waters at substantially higher rates than atmospheric CO2 alone.

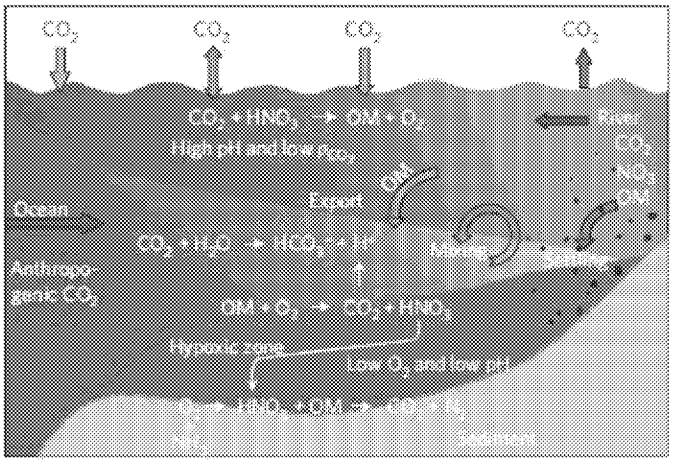
These non-atmospheric inputs can have particularly large consequences when they coincide with biotic phenomena [e.g., spawning events or abiotic processes, such as upwelling events that bring low-pH water to nearshore areas. Additional local phenomena— such as sulfur dioxide precipitation, hypoxia, eutrophication , and both emissions and runoff from acidic fertilizers—can intensify these localized hot spots. These impacts are likely to be magnified when combined with other stressors in the coastal ocean, including overfishing, habitat destruction, temperature increases, and nonacidifying pollution.

As global and national efforts to mitigate CO2 emissions struggle to gain traction, smaller-scale actions become increasingly important. In the United States, for example, local and state governments have both the authority and motive to address many stressors that drive or exacerbate acidification conditions. This runs contrary to the widely held

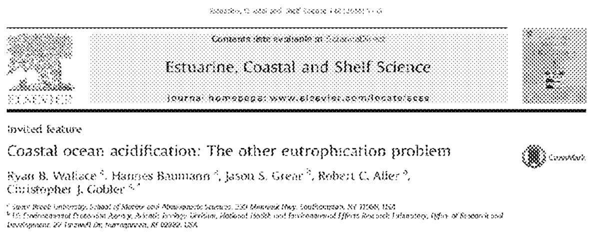
perception
that acidification cannot be addressed at the scale of local (e.g., municipal and county) or regional (state, multistate, and territorial)
Jurisdictions.

Coastal Acidification + Eutrophication

- Nutrient and organic matter delivery (up)
- Respiration and CO_2 (up)
- pH and $CaCO_3$ saturation state (down)



"Eutrophication-induced acidification may currently be a more common phenomenon then upwelling-induced acidification that occurs on the US West Coast. Clearly, more studies of coastal ocean acidification will be required to evaluate this hypothesis."


Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Invited feature

Coastal ocean acidification: The other eutrophication problem

Ryan B. Wallace[a], Hannes Baumann[a], Jason S. Grear[b], Robert C. Aller[a], Christopher J. Gobler[a,*]

The Seattle Times

Shellfish at risk: Puget Sound becoming acidified

The waters of Puget Sound and Hood Canal are becoming more acidified as a result of rising carbon dioxide from industries, power plants and vehicles. Scientists from the University of Washington and the National Oceanic and Atmospheric Administration warn that the shifting water chemistry could damage the region's shellfish industry.

The Seattle Times

Oysters in deep trouble: Is Pacific Ocean's chemistry killing sea life?

Oyster larvae have been dying by the billions. Scientists suspect it's a sign that carbon dioxide is dramatically affecting the ocean — and if they're right, it could push Washington into the center of the debate about the future of the seas.

PBS NEWSHOUR

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REPORT AIR DATE: Dec. 7, 2012

Trouble in the Water: Acidifying Oceans Hinder Health of Northwest Shellfish

Are Oysters Doomed?

Don't believe in climate change? Talk to a clam digger.

Los Angeles Times

Oceans' rising acidity a threat to shellfish — and humans

By Kenneth R. Weiss, October 6 2012

As carbon dioxide continues to build up in the atmosphere as a result of burning fossil fuels, the seas absorb much of it. The full effects have yet to be felt.

The New York Times March 12, 2010

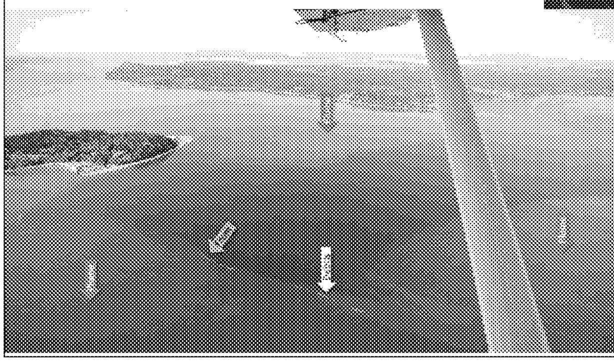
Some See Clean Water Act Settlement Opening New Path to GHG Curbs

Lots of press, resonating with the public and state governments (e.g., govenors). PNW is at the center of this issue.

The first sign of biological impacts in the PNW appeared within the last decade. From 2005 to 2009, two commercial shellfish hatcheries in Washington and Oregon suffered massive die-offs of Pacific oyster larvae. During that same timeframe, wild Pacific oysters in areas of the Pacific Northwest where they have naturalized failed to successfully reproduce. The failed natural reproduction coupled with significant hatchery production problems in two of the main West Coast shellfish hatcheries threatened the viability of much of the West Coast shellfish industry, which is dependent upon hatcheries and wild reproduction for seed.

Initially, the die off of larvae in hatcheries was thought to be caused by blooms of a strain of bacteria called Vibrio tubiashii flourishing in oxygen-starved dead zones. As hatchery operators, researchers, and others worked to understand the source of the problem, an alternate theory emerged: that the ocean's absorption of anthropogenic CO2 was increasing the concentration of hydrogen ions and reducing the pH and the dissolved carbonate ion concentration, as well as the aragonite and calcite saturation states of coastal marine waters, which was having a significant and adverse effect on larval oysters' ability to form shells.

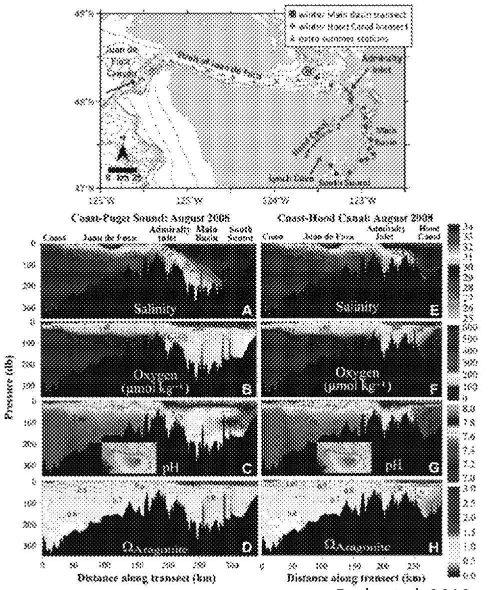
R10 – ORD RARE 2015 Project



EPA Region 10: Ocean acidification and eutrophication in the Salish Sea

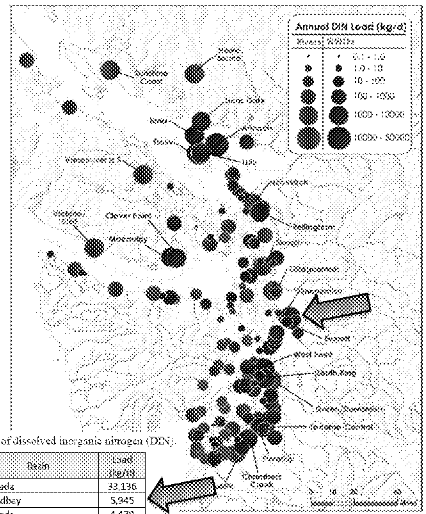
Multiple stressors leading to coastal acidification

1. Upwelled oceanic water intrusion (high CO_2, low O_2)



Feely et al. 2010

2. Eutrophication via river and WWTP inputs



rganic nitrogen (DIN) loads from rivers and WWTPs

Mohamedali et al. 2011

Table 7. Top 20 watershed contributions of dissolved inorganic nitrogen (DIN).

Rank	Watershed	Basin	Load (kg/d)
1	Fraser	Canada	33,136
2	Snohomish	Whidbey	5,945
3	Sunshine Coast	Canada	4,479
4	Nooksack	Canada	4,176
5	Skagit	Whidbey	4,224
6	Stillaguamish	Whidbey	2,441
7	Puyallup	Commencement Bay	2,105
8	Victoria/SJdF	Canada	2,039
9	Vancouver Isl S	Canada	1,777
10	Green/Duwamish	Elliott Bay	1,635

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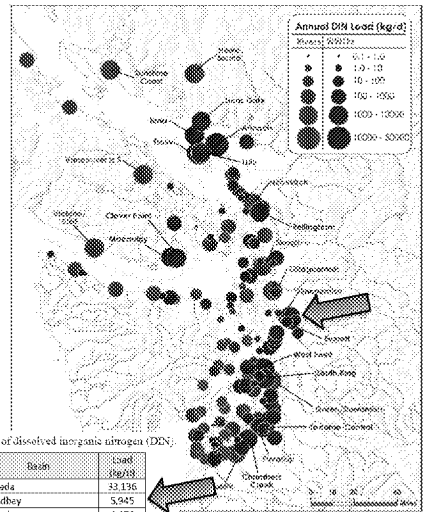
Study site location: Snohomish Delta



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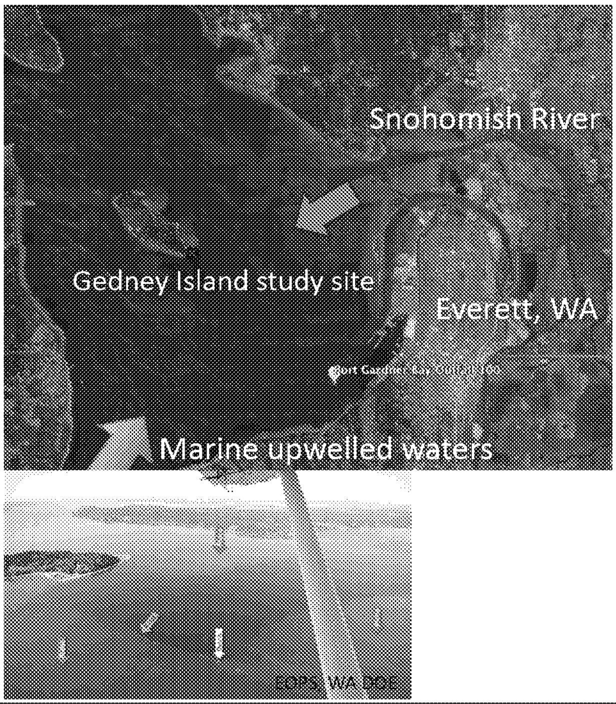

- Large nutrient inputs from river and wastewater sources
- Exposed to marine, upwelled waters
- Ecologically important for salmon and shellfish harvests
- Tulalip Tribal interests

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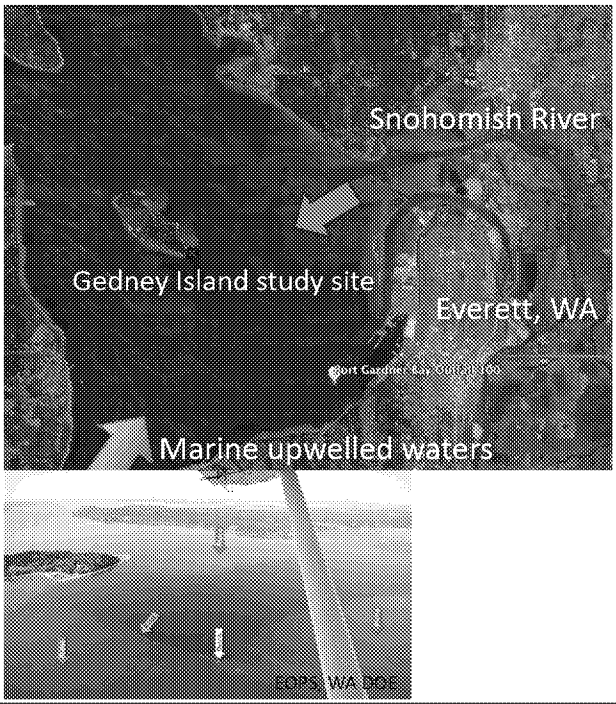

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EPA Region 10: Ocean acidification and eutrophication in the Salish Sea

Multiple stressors leading to coastal acidification

Research goals:

Field site photo here

1. Characterize the variability of carbonate chemistry and oxygen dynamics experienced by a shellfish bed under oceanic and riverine influences

2. Quantify the relative contributions of natural and anthropogenic nitrogen sources to water column primary production

3. Quantify potential departures in magnitude, frequency, and duration of carbonate chemistry variability from natural conditions due to respiration driven by anthropogenic nutrients

EPA Region 10: Ocean acidification and eutrophication in the Salish Sea
Multiple stressors leading to coastal acidification

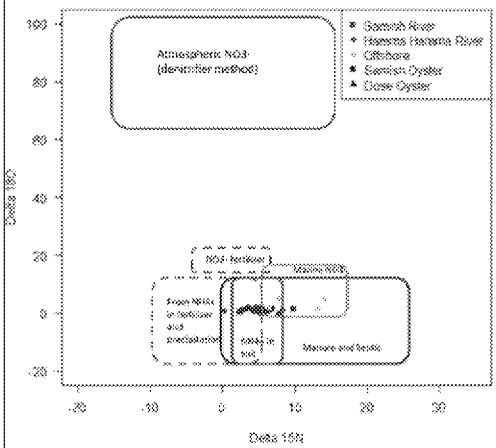
Project timeline

Collaborations

Tulalip Tribes
EPA Region 10
EPA ORD – Western Ecology Division
Washington Department of Ecology
Pacific Northwest National Laboratory
Oregon State University

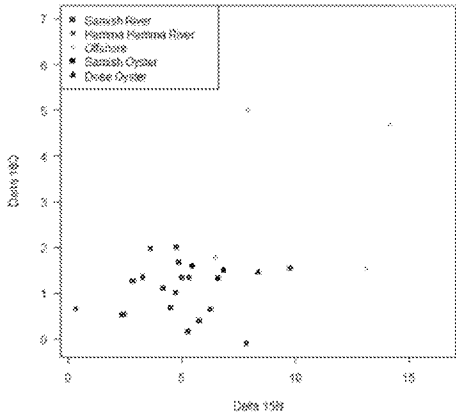
Products? Mention of papers – conferences?

Questions



A1. Delta 15N and delta 180 values for water nitrates collected in the Sa
Hamma rivers (including river mouths) and the Samish and Dosewallips
values crudely redrawn from Kendall et al. (2007).

Conway-Cranos et al., unpublished?



A2. Delta 15N and delta 180 values for water nitrates collected in the Samish and Hamma Hamma Rivers and the Samish and Dosewallips oyster beds.

Extra slide - Evidence for importance of non-marine nutrients to local primary production and trophic support of shellfish